The Effects of Grazing and Climate Warming on Plant Species in the Faroe Islands

Kolbrún í Haraldsstovu

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Swedish University of Agricultural Sciences, SLU
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Department of Ecology
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The Effects of Grazing and Climate Warming on Plant Species in the Faroe Islands

Ávirkanin av seyðabiti og veðurlagsbroytingum á plantusløg í Føroyum

Kolbrún í Haraldsstovu

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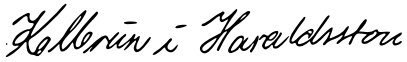

Contents

Abstract

The Faroe Islands are composed of eighteen small islands situated in the middle of the North Atlantic Ocean. Heavily affected by grazing and harsh weather conditions, the mountaintop vegetation is exposed to multiple environmental pressures. In this project I examined the effects of climate warming and grazing on Faroese plant species. Three different treatments were used; an inside fenced area containing nine plots to exclude grazing, and another ten plots with Open Top Chambers simulating climate warming and finally nine plots outside the fenced area, which are consistently exposed to grazing. Since 2001 high resolution photographs have been taken of the plots, for this study, the years 2007 and 2017 being chosen for comparison. I developed a new method of plant cover estimation for this study involving placing a digital quadrat on each photograph within which the cover of nine different plant species was estimated.

The frequency of several plant species was observed to increase over the 10-year period, as well as the overall plant diversity. Exceptions included *Euphrasia* which showed a negative response to grazing, *Salix herbacea* and *Silene acaulis* which were negatively affected by experimental warming, and *Ranunculus acris* which responded positively to experimental warming. The difference in responses to the environmental pressures examined could be attributed to various reasons; functional plant traits, adaptive resilience and short term vs. to long term responses, amongst others. The continuation of this monitoring study will help connect interactions between the different global drivers of change and resulting effects on plant diversity in a region where climate consequences are largely unknown.

Úrtak

Føroyar, eitt lítið oyggjasamfelag, liggja mitt í Norður Atlants havinum. Gróðurin er sera nógv ávirkaður av seyðabiti og sum heild er veðurlagið ógvuliga ábært og vindhart. Hetta merkir at fjallagróðurin í Føroyum er undir nógvum umhvørvisligum trýsti. Í hesari uppgávu vóru ávirkanin av hita og seyðabiti á ymisk plantusløg á føroyskum fjøllum kannaði. Níggju innhegnaðar støðir sum útihýsa seyði vórðu kannaðar. Somuleiðis vóru kannaðar tíggju støðir, sum eftirlíkna eitt heitari veðurlag og níggju støðir uttanfyri hegnið, har seyður hevur atgongd, kannaðar. Góðskugóðar myndir hava verið tiknar av hvørjari støð síðani 2001, og árini 2007 og 2017 vóru samanborin í hesi kanning. Ein nýggjur granskingarháttur varð gjørdur í samband við hetta kanningararbeiðið. Ein talgildur kvadratur varð teknaður á hvørja mynd og síðani vóru plantu sløgini eyðmerkt og tald.

Sum heild vístu úrslitini at plantusløgini koma seg væl hóast seyðabit. Yvir eitt 10-ára tíðarskeið vuksu tær flestu meira enn tær vóru etnar, og sum heild hækkaði plantuliga margfeldið í hesum tíðarskeiðinum. Kortini vísti tað seg at seyðabit hevði eina negativa ávirkan plantuslagið *Euphrasia.* Tvey sløg, ávíkavíst *Salix herbacea* og *Silene acaulis* vóru negativt ávirkað av hita, hinvegin vísti *Ranunculus acris* seg at tola hita væl. Orsøkin til at plantusløgini vóru ymiskt ávirkaði av kannaðu umhvørvis trýstum kunnu vera fleiri; planturnar kunnu hava ymisk virkiseyðkenni, sum gera tær meiri mótstøðuførar enn aðrar. Eisini kunnu tær hava tillaga seg til náttúruumhvørvið í Føroyum. Ein grund kann eisini vera at stutttíðar kanningar, sum hendan, vísa øðrvísi úrslit enn langtíðar kanningar. At enda hevur tað alstóran týdning at hendan eftirlits kanning heldur fram soleiðis at sambindingarnar millum tey drívhjól handan umhvørvisbroytingar gerast sjónligari og eru við til at lýsa ávirkanina á plantuliga margfeldið í einum øki har avleiðingar av veðulagsbroytingum enn eru ókendar.

Popular science summary

Small Islands with a global importance

In the middle of the North Atlantic Ocean lies the Faroe Islands archipelago. Characterized by steep green mountains and roaming sheep, these islands situated between Scotland and Iceland are so small that they are not even visible on the world map! Nevertheless, they are a very important study site on a global scale as their remote location in the North Atlantic makes predicting future climate scenarios and warming consequences very difficult, so any information rendered in this region becomes particularly valuable.

In the Faroe Islands, there are around four times as many sheep as people, and with these animals having access to nearly the entirety of the islands' terrain the native mountain vegetation is heavily affected by these grazers. The islands also experience very harsh weather conditions with heavy wind and storms each winter. Combining these two factors, the grazing and the heavy wind is thus not a great cocktail, it can lead to erosion on the mountain sides which results in increased bare ground. Many plant species are now only found in inaccessible places as a consequence of this and because of the heavy grazing on the islands. You can imagine that if we consider climate change as a reinforcing factor in all of this, how much the vegetation on the islands could be affected in the future! If the temperature was to increase and the heavy grazing continued, the plants would not only experience the grazing pressure, but a temperature pressure as well. This is why studying the interactions between grazing and climate change now is especially important.

The overall results in this study showed that most of the plant species examined are able to withstand grazing pressure. In a future warming scenario however, there will be both positive and negative plant responses. Why do plant species respond differently to environmental pressures? There can be several reasons for this. One theory is that plants may have adapted a form of resilience against the sheep grazing, after having coexisted together with the animals on the islands for hundreds of years.

This study occurred over a time span of 10 years, and the plants are very slow growing. Knowing this it is important to consider the observed results may be short-term plant responses which could differ substantially from long term responses. It could also be that the plant species possess different traits that make them differ in their resilience

strategies, for example the ability to disperse seeds and their reproduction rate can influence how well they can withstand increased temperature.

Continuing this study will help clarify how the short-term plant responses may differ from long-term and fill the knowledge gap of potential climate consequences in this region. It is critical to gain a better understanding of which interacting factors drive the change in mountain environments and implement the research into a global context to understand how future biodiversity may be affected.

Introduction

Climate change and other anthropogenic pressures

The recent climate warming is predicted to be one of the main factors driving species to extinction in the future (Midgley & Hannah, 2019). As an example, in many species, natural history traits are triggered by temperature related-cues that influence the timing of events such as migration, flowering and egg laying (Root et al., 2003). Species interactions are being altered because of climate change and are causing local species extinctions. Consequential changes in community structure have been observed due to changes in plant interactions and growth mediated through climate warming (Baruah et al., 2017).

The largest threat to species worldwide is currently habitat destruction in the form of land use change (Auffret & Thomas, 2019; Newbold et al., 2015), in North Western Europe grassland abandonment being one example (Habel et al., 2013). These modifications caused negative trends across population and community levels in different taxonomic groups, for instance through disrupting the connectedness among species, leading to reformulation of species communities which can result in extirpations and possible extinctions (Root et al., 2003). Besides climate warming, another anthropogenic pressure on biodiversity is the arrival of non-native species. Tourism is one such contributor to the spread of non- native plant species to protected areas such as national parks (Anderson et al., 2015) , leading to increased competition between the invasive and native species in some cases (Vilà & Weiner, 2004). As a result of this, community richness and composition has been altered over time (Auffret & Thomas, 2019).

These three named drivers of global change -climate warming, habitat destruction and arrival of invasive species- have been known to interact and together cause changes in populations over time. Species have for example been failing to expand their ranges following climate change as a result of past habitat destruction. Furthermore, in areas exposed to high levels of habitats modifications, climate change has shown to compound population declines (Auffret & Thomas, 2019).

Temperature changes in the northern hemisphere

Northerly regions of the world are experiencing a much higher rate of climate warming compared with the equator. The increase of temperature has been observed at approximately 0.09 °C per decade over the last 100 years, with larger regional variations (IPCC, 2014). It is predicted that the increase will continue over the course of the twenty-first century, the best estimates ranging between 1.8 °C to 4.0°C per decade, depending on the scenario and model used (IPCC, 2014).

The response to climate change in the arctic tundra is rapid (IPCC, 2014). Since 1978, annual arctic temperatures have increased by more than 2°C (Ciais et al., 2013). Sites around the tundra biome display growing evidence that warming leads to changes in vegetation communities (Grabowski et al., 2019). These changes include changes in vegetation composition (Elmendorf et al., 2012), and plant phenology (Post et al., 2009) and more recently yet unexplained high heterogeneity in vegetation responses (Myers-Smith et al., 2015; Prevéy et al., 2019).

Mountains and climate warming

Due to the compression of thermal zones and orographic isolation caused by low-temperature conditions, mountains host a large fraction of Earth's biodiversity. Cold temperatures and short growing seasons largely determine the occurrence of high-mountain species. It is anticipated that a higher rate of climate warming will happen in mountain ecosystems compared to most other regions (IPCC, 2014).

Many reports dealing with redistribution of species towards summits and changes in biodiversity because of warming, suggest that mountain biota is extremely sensitive to increases in temperatures. The now accelerating trend in temperature increase that is occurring is therefore expected to effect the rate of changes detected for mountain biota (Steinbauer et al., 2018).

There are three basic ways in which mountain plant species may respond to climatic change: persistence in the modified climate, migration to a more suitable climate; or extirpation. Plant species are more likely to persists in more larger and diverse populations where the temperature change can be buffered through phenotypic plasticity, gradual adaptions or genetic modifications. Greater population genetic and ecological diversity is expected to lead to higher resilience (Theodoridis et al., 2018).

Negative consequences on population persistence may ensue as a result from these responses, one example being competition between alpine plants and species from lower elevations migrating northward. Mountain ranges possess a large proportion of species endemic to lowland areas, so this could result in critical biodiversity losses in areas of higher elevation due to species competition (Gloria, 2020). Other factors such as fragmentation (natural barriers such as steep mountains that limit seed dispersal; Theurillat & Guisan, 2001) and plant/animal interactions (e.g. ecosystem modification through herbivores' selective feeding, thus changing vegetation composition over time ;Motta, 1996) can also play a significant role in plant species' population dynamics.

Another factor that should be considered in conjunction with the effects grazing and climate change is genetic diversity (Crawford & Whitney, 2010). High genetic diversity will increase the probability of a species to both colonize new habitats and resist climate change. Furthermore, there is indication of a link between genetic and ecological diversity, as a positive correlation often exists between heterogeneity and overall genetic variation across occupied habitats (Theodoridis et al., 2018). As a consequence, species with high genetic diversity are more likely to cope with a broader set of climatic conditions because they likely have a broader ecological niche than less genetically diverse species (Theodoridis et al., 2018).

Grazing in alpine and subalpine environments

Recent research on the effects of sheep grazing on mountain biota remains minimal. (Austrheim & Eriksson, 2001; Fosaa, 2015; Fuhlendorf, Briske, & Smeins, 2001), with more work being focused on reindeer grazing in northern areas (Olofsson, 2006; Olofsson et al., 2009; Suominen & Olofsson, 2000). These studies conclude that reindeer grazing increases richness and diversity of the vegetation depending on the grazing intensity, moderate levels producing the strongest enriching effect. Historical human survival in mountainous alpine environments was steeped on traditions that overtime heavily impacted natural resources, particularly raising livestock over the course of centuries. As humans have had an impact in a historical and maybe even an evolutionary time scale, producing positive effects on plant diversity, this land use regime should be taken into consideration when defining sustainability from a biodiversity perspective (Olsson, Austrheim, & Grenne, 2000). Nonetheless, it is critical to find an optimal grazing amount,

that is seen as both ecologically and economically sustainable as well as one that continues to maintain the biodiversity in these systems (Austrheim & Eriksson, 2001).

Herbivory effects on species diversity depends on several factors, namely type of grazer, grazing intensity, frequency as well as different habitat attributes, such as productivity, climate and evolutionary history, and the reginal pool of potential colonisers also factor in (Hobbs & Huenneke, 1992).

Natural grazing with semi-domesticated reindeer and sheep generally occurs in Alpine ecosystems. Yet having had this tradition for centuries, the long-term effects of herbivory across the northern ecosystems as well as short timescale changes in plant community structure have been understudied and there is little data to support many hypotheses. Particularly scare are impacts on a local scale in successional processes which result in a regional vegetation mosaic (Austrheim & Eriksson, 2001).

Factors controlling species richness in plant communities

Two main factors exist that control plant communities' species richness in the northern mountains. The first are abiotic factors that include annual and seasonal variation in snow distribution affecting microclimate, soil moisture, and nutrient availability (Austrheim & Eriksson, 2001). It is found that species diversity on a local level is positively correlated to base-rich sites (Austin, 1999).

The second major factor that controls species richness, is grazing. The local structure of alpine plant communities strongly influenced by grazing include community composition and specific taxonomical group's density (Austrheim & Eriksson, 2001). Grazing animals positively affect ecosystems in numerous ways by defoliating, treading, and leaving excreta, amongst others (Duncan, 2005; Metera, Sakowski, Słoniewski, & Romanowicz, 2010). Another significant way in which grazers influence plant diversity, is through seed dispersal (Olff & Ritchie, 1998a).

Austrheim & Erikkson (2001) suggest that plant productivity interacts with grazing effects. Plant species richness is generally favored by grazing in both high and lower productivity communities alike (Oksanen et al., 1981). However, in extremely low-productive communities, plant species richness is negatively affected by grazing. On the other hand, moderate grazing can contribute to an increase in plant species diversity and ecosystem stability (Wang & Tang, 2019). A community in continuous change will

therefore more easily maintain its diversity, and diversity will remain higher at a scale of intermediate frequency and intensity of disturbances (the intermediate disturbance hypothesis; Connell, 1978). Thus, in a community at equilibrium, no grazing can also decrease diversity. A study by Cheng et al. (2011) demonstrated this where plant diversity increased at a light grazing intensity level, but decreased at a moderate and heavy grazing level.

In conclusion, it is difficult in general to predict the grazing impact on plant diversity, as the effects of other hypothesised factors that play a role together with grazing (i.e. grazing intensity and frequency, productivity, and climate) have not been explicitly studied together (Austrheim & Eriksson, 2001).

Colonisation and persistence of previously established populations are two basic processes that govern the composition of plant regional plant dynamics (Eriksson, 1996). Vegetative structure and diversity at each local patch is affected by grazing disturbance, which presumably can be correlated to grazing intensity. A temporary local shift towards a grazing-modified plant community will be imposed by the grazer at one point in time, while continuous extensive grazing at a particular site will make the shift nearly permanent (Austrheim & Eriksson, 2001). Each site will recover, however, if the grazers move to other sites thus make the grazing patchy. The recovery time depends on the frequency of grazing in particular sites and determines the regional permanency in vegetation structure and diversity. Regional dynamics of the plant species that inhabit the grazed community determine the resilience of the site. Resilience increases with the capacity to maintain remnant populations (Eriksson, 2000).

Alpine plants mostly consist of long-lived perennials with the possibility of clonal propagation. This is expected to aid in the general persistence on a local scale (Molau, 1993). The ability of individual plants to withstand grazing (plant palatability) or recovery after grazing is vital for the persistence of the species, as well as the indirect effects on competitive relationships among species (Augustine & McNaughton, 1998).

From a climate perspective, grazing effects need to be considered when studying climate change effects on biota, particularly in ecosystems where grazing is the dominating land use factor (Fosaa, 2015). Olofsson et al. (2009) showed in their study that the abundance of shrub vegetation is controlled by an interaction between climate and herbivores

because of a positive relationship that exists between shrub growth in the absence of herbivores and annual mean temperature and the lack of relationships in grazing plots. Cheng et al. (2011) suggests that the vegetational response to grazing pressure becomes questionable in the context of climatic variability because little is known about the interactions between grazing and climate warming. These two factors occur on numerous spatial and temporal scales, thus affecting the vegetation differently, making it difficult to assess (Fuhlendorf et al., 2001).

Future predictions of vegetational changes

The species that experience the most severe range shifts due to climate change are cold-adapted plants growing at high latitudes and altitudes. Predictions state that a significant reduction of climatic suitable habitats for mountain floras will happen by the year 2100 and therefore biological biodiversity will suffer a great loss (Dullinger et al., 2012). Even so, some studies have suggested beneficial effects of climate change on cold-adapted species, more specifically how it could lead to expansion to newly available habitats (Theodoridis et al., 2018).

Tundra vegetational changes are expected to have far-reaching impacts that also affect other trophic levels and human societies. Trophic mismatches starting at pollinator resources, carrying over to mammals and birds on an individual as well as population level could happen as a result of shifts in plant reproductive and phenological success (Bjorkman et al., 2020).

Other monitoring measures involving vegetation show that total plant cover is increasing in the tundra ecosystems while bare ground is decreasing. An indication of a shift towards an increased deciduous shrub cover and expansion is evident in the measurable composition change, as well as a graminoid cover (Elmendorf et al., 2012). Shrubs are dominant species owing to their ability to outcompete low-growing plants due to their canopy height and longevity. This makes them well suited to dominate the tundra biome in a changing climate (Myers-Smith et al., 2015). Other warming experiments have shown the same results, suggesting that the drivers behind these vegetation changes are in part related to increasing temperature (Elmendorf et al., 2012).

Predictions of vegetational changes due to grazing are centred on predictable stepwise transitions from one vegetation state to another. As an example, lichen-dominated

regions transitioning to moss dominated vegetation in northern and arctic areas as a result of herbivory (Van der Wal et al., 2001). Another is moss-dwarf shrub heath transitioning to grass dominated tundra (Olofsson, 2006; Olofsson, Stark, & Oksanen, 2004), occurring in both alpine Scandinavian areas (Austrheim & Eriksson, 2001; Wielgolaski, 1975) and Scottish uplands (Alonso, Hartley, & Thurlow, 2001). The capacity to sustain a greater herbivore population could be expected to increase as a result of transitions toward a grass dominated vegetation (Van der Wal, 2006).

The Faroe Islands

In the middle of the North Atlantic Ocean lies the Faroe Islands archipelago, composed of eighteen isolated islands situated between Scotland and Iceland. Belonging to Denmark, but have held own home rule government since 1948 (Danielsen & Agnarsson, 2018).

The islands encompass a total area of 1399 km^2, extending 113 km from the North to South and 75 km from the East to West. The northern islands possess the highest elevations, reaching nearly 890 m above sea level (Cappelen & Laursen, 1998).

The Gulf stream as well as the passage of frequent cyclones, greatly influences the regional climate. They arrive from the south and west depending on the position of the polar frontal zone. This results in a humid, unsettled and windy climate with mild winters and cool summers, where the annual mean precipitation is around 1500mm in the lowlands (Cappelen & Laursen, 1998). On the mountaintop (726 m a.s.l) the mean annual temperature is a mere 1.7°C. February is the coldest month with a mean temperature of -2.0°C, while in summer, the average is near 6.5°C, most notably in August (Fosaa, 2015). Being located in the North Atlantic current, future potential vegetation changes become more difficult to predict because of the uncertain future climate development in this region (Fosaa, 2003b). Some climate models for the 21st century have predicted a possible weakening of the North Atlantic current, being supported by some observations. Should this occur, the result of this would be a temperature decrease in the Faroes rather than an increase. Assessing the future vegetational changes of the Faroe Islands thus requires an inclusion of both warming and cooling scenarios (Fosaa, 2003b)

Vegetation on the Faroe Islands

There have been various vegetational changes in the Faroe Islands since the last ice age. These changes are the result of a fluctuating climate, and additional human influence since the first settlement occurred (Fosaa, 2015). On the islands today, about 400 species

of flowering plants and 27 pteridophytes have been recorded. Of the flowering plants only 310 are considered indigenous. There are 30 species which have become naturalized of the 90 species which have been present since settlement. The other 60 exist as weeds in urban areas or cultivated lands (Hannon et al . 2001). The flora on the islands is mostly comprised of perennial herbaceous plants. A distinct vertical zonation exists in the vegetation, cliff regions containing species such as *Angelica archangelica*, *Cochlearia officinalis* and *Silene dioica*, whereas in the highest altitudes, flora with an arctic element dominate together with rushes (*Juncaceae*) (Hannon et al., 2001). Grasslands are the dominating vegetated ecosystems on the Faroe Islands, especially in the lowlands and mid-altitudes allowing sheep access to nearly every terrain. Consequently, soil erosion is common as a result of intensive grazing that leads to thin topsoil formation. The steep mountains on the islands also factor into the increasing bare soil (Fosaa, 2015).

The Faroe Islands are particularly suitable for studying the effects of grazing and climate change as long-term studies of the biotic response to environmental change are especially well suited to take place on mountain summits. This is because they are representations of a natural permanent study site with an easy relocation over time, making it possible to record reliable time series (Steinbauer et al., 2018). Grazing has occurred on the Faroe Islands for more than a thousand years, and records show the vegetational changes have been extreme (Fosaa, 2015). Due to genetic and demographic factors, intensive grazing can heavily impact plant populations on islands (Egelund, Pertoldi, & Barfod, 2012). The only untouched vegetation that remains now occurs in clefts, raciness or on the most inaccessible slopes (Jóhansen, 1985). As mentioned previously, little is known about the interactions between grazing and climate, therefore promoting this research on an isolated archipelago with large future climatic uncertainty where other environmental stressors contribute to the effects on the vegetation is crucial.

Vegetational changes in coastal and oceanic areas

Compared to continental areas, vegetational changes in coastal and oceanic areas have in largely not been given the same degree of scientific attention. Considering that the temperature range in oceanic and coastal areas is relatively small during the year, this difference would perhaps require individual consideration from continental areas (Fosaa, 2003b). The oceanic areas in the North Atlantic have been particularly lacking in attention, yet climate warming predictions state that oceanic areas in NW Europe will

include increased precipitation and cloudiness, and perhaps also windspeed (IPCC, 2014).

Aim of study

The aim of this study was to assess the effects of grazing as well as climate warming in the absence of grazing on Faroese mountain plant species. Reflections were also made on the potential consequences of future climate change on mountain biota where grazing could behave as a reinforcing stress factor.

This project was furthermore an effort to continue the work of Anna Maria Fossá, who did important research on the effects of climate warming on mountain vegetation in the Faroe Islands before her sudden passing.

Grazing chiefly affects plants, but because of this activity's long history on the islands, this effect may have reduced. It was predicted however that most plant species would decrease in abundance over the span of this monitoring study, primarily due to the intensity of grazing recorded on the Faroe Islands. Furthermore, it is hypothesized that as Faroese vegetation is particularly vulnerable to an increase in temperature, the result of their remote location, in seed dispersal rate would also decrease while clonal reproduction increased. In other words, the genetic diversity within the plant populations would be lower because of this and thus vulnerable to rapid environmental change. The effects of climate on the Faroese plant species were therefore anticipated to be evident.

Methods

Study area

The mountain of Sornfelli (62°04´N, 6°57´W) at 600 m a.s.l. was used as the study area, located on the on the island of Streymoy in the central region of the Faroe Islands. Open grass land as well as *Racomitrium* heath vegetation dominate the area. *Silene acaulis* and *Polygonum viviparum* are the most frequent herbs out of the 25 species of vascular plants that have been recorded on the from the site. Frequent noted grasses include *Agrostis capillaris, Agrostis canina, Festuca vivipara* and *Desampsia flexuosa.* The only woody species, *Salix herbacea*, is also frequently observed (Fosaa, 2015). Sheep graze the whole area, about 45 ewes per km2 (Thorsteinsson, 2001), as well as hares and geese.

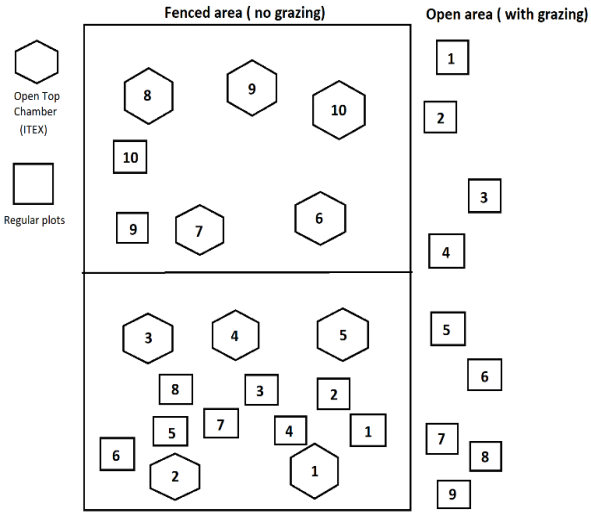

Figure 1, overview over monitoring set-up. Every plot is represented by a number.

The International Tundra Experiments (ITEX)

Warming and grazing experiments have been carried out on the Faroe Islands for almost two decades. For this project, data from an existing monitoring program set up in 2001 on the mountain Sornfelli was used.

ITEX is a collaborative network of researchers with the goal to examine the warming impacts on tundra ecosystems, using common temperature manipulation (Photograph 2). Specifically, how species responses vary across climatic and geographic gradients of tundra ecosystems. The overall results from these experiments have predicted that warming will cause a decline in biodiversity in tundra ecosystems, at least in the short term (Arft et al., 1999). Other ITEX experiments show that responses vary among species and plant communities, indicative of community-warming interactions. More importantly, it shows the possibility of great variation between plant species and their ability to continue in a positive growth response long term, causing shifts in their relative competitive ability (Baruah et al., 2017).

This master's project was carried out as a part of these long-term experiments.

Two experimental areas were used in this study. Inside an experimental fenced area two different treatments were applied to individual areas. The first consisted of nine replicate plots that excluded grazing animals, which was named "*without grazing"*, (Photograph 2), the second, named "*experimental warming*" containing ten replicate plots inform of Open Top Chambers (OTC) which aid in inducing experimental climate warming in relative controlled conditions (Photograph 1). These chambers warm the vegetation approximately 1-3 °C. Outside the fenced area was the second area, where the third and last treatment was set up with nine replicate plots which were consistently exposed to grazing, named "*with grazing"*. All plots measured 50x50 cm. The overall monitoring set-up can be seen on Figure 1.

Photograph 1, replicate plot 10, Experimental warming treatment (2017)

Photograph 2, replicate plot 1, without grazing treatment (2017)

Digital plant identification

I developed a new form of method for this project using high resolution photography. Photos taken of the plots every summer since their set up in 2001 were used for plant identification. A digital quadrat (5x5 sub squares) was placed on every photograph (Photograph 1 & 2).

Around 25 vascular plant species have been registered in the area, and from the most abundant plant species, nine species were selected to be identified within each photograph. This was done not only because of plant abundance, but also as the chosen

species were considered more easily identifiable via digital photograph. The plant species chosen included the woody species *Salix herbacea*, and the herbs *Bistorta vivipara, Silene acaulis, Ranunculus acris, Armeria maritima, Rumex acetosa and Euphrasia.* Two frequent grass species were also chosen, *Festuca sp.* and *Agrostis sp.* The most common Festuca species on the Faroe Islands include *F. vivipara, F. pratensis* and *F. rubra,* and the most common Agrostis species are *A. capillaris, A. canina, and A. stolonifera* (Jóhansen, Fosaa, & Rasmussen, 2000).

Every photograph was manually inspected by me only, to exclude an observer effect. Plant observations were made through identifying specific morphological traits of each species visible within each photograph.
Each species was counted as present or not present within each of the 25 subplots of the quadrat (one replicate plot). Species richness was then measured for each treatment; the abundance of each of the nine species being counted in every replicate plot for each of the three treatments. Lastly the total vegetation cover was estimated in percentage for each replicate plot. For this project, the summers of the years 2007 and 2017 were chosen for comparison, in order to look at change over time, as e.g. plants can be slow to respond to external stressors. In total I went through and identified nine plant species in 52 photos, thus 52 different plots for this study. The photograph with the highest quality of each plots was chosen to facilitate plant identification. However, photo resolution between pictures from the years 2007 and 2017 varied which may have impacted the accuracy of some species identification.

Statistical analysis

Analysis of variance was performed on the frequency of the nine study species as well as species richness and vegetation cover using the statistical program JMP. Two sets of models were then performed. One analysis of variance to assess the effects of grazing by comparing the grazed versus the non-grazed treatments while the other analysis of variance was made to assess the effects of climate by comparing the warming treatment (OTC) with the non-grazed treatments. The warming treatment was thus only assessed in the absence of grazing, using the non-grazed plots for comparison and grazing was only assessed in the absence of warming. For the species level models, the response variable

was species frequency (where the 25 subplots was =100%) while the predictor variables were treatment (grazed or ungrazed and OTC), year (2007 or 2017) and the interaction between treatment and year. The response variable for the species richness was the total number of species occurrences in each plot for each treatment, and for the vegetation cover it was an estimation ranging from 0-100%. The predictor variables were the same for the richness and cover as for the species level models. A standard ANOVA was carried out for the diversity measures as well. In total there were 22 analysis of variance models of analysis of variance. One for each species, as well as richness and vegetation cover, both for Climate*Time and Grazing*Time.

Results

Vegetation cover

The vegetation cover for the non-grazed and grazed treatments both started with approximately the same mean cover percentage of 30% in 2007 (Figure 1, A & B). The non-grazed treatment showed a greater increase in cover over time, unlike the grazed treatment which did not show a high increase from 2007-2017. Overall vegetation cover was significantly higher in the warming treatment for both years. In 2007 it was already around 80%, reaching 100% by 2017 in all plots (Figure 1, B). The vegetation in the OTCs however seemed to be dominated by bryophyte growth. The p- value of the test statistic indicates that the null hypothesis of "no change" can be rejected at the 5% level. This means that there exists a very convincing significance in the warming treatment.

The monitoring experiment was set up in 2001, and therefore it can be assumed that the vegetation cover was the same for all plots in 2001. This indicates there was a significant growth inside the warming treatment compared to the other two treatments, however, the year 2017 showed increased vegetation cover for all treatments, compared to 2007.

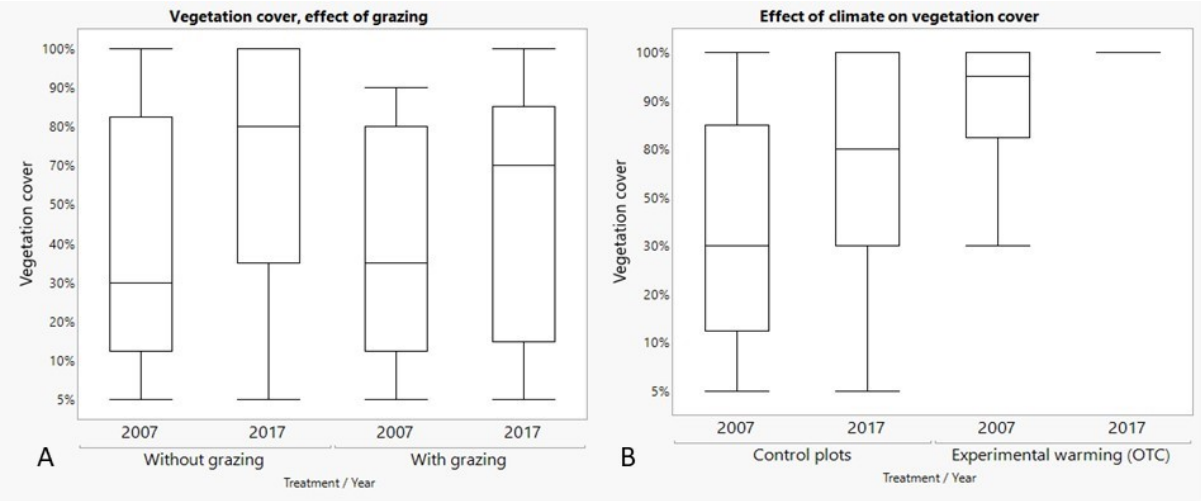

Figure 1, box plots with the effects of climate and grazing on vegetation cover.

Diversity

Species richness was highest in the year 2017 for all treatments (Figure 2). It did not vary much between the grazed and non-grazed treatments for this year, most plots having between 7-8 (out of 9) species present, while the warming treatment possessed a mean of 6 species, respectively. Regarding the 6 and 16 years following the exclusion of grazing and the experimental warming, community diversity was lowest in 2007. The warming treatment has the highest number of species, while the grazed and non-grazed treatments had between 4 and 6. None of the three treatments contained all test species, and no treatment had fewer than 4 species.

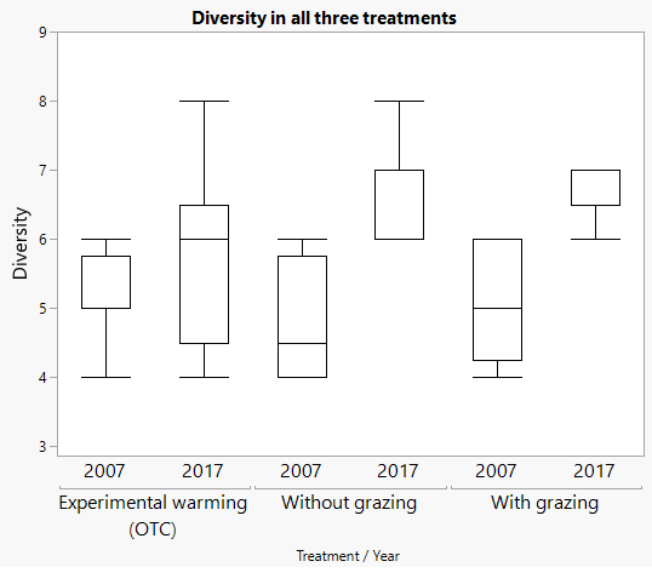

Figure 2, boxplot with the diversity results for all treatments. X-axis shows the plant species from 0-9 and y-axis shows the three treatments and years chosen.

Individual plant analysis

Tables 1 and 2 show the results of the nine plant species chosen in this study. The six species showing significant results (i.e. increased or decreased in frequency in treatment or year over time) have been highlighted in this section with regards to the effect of experimental warming in the Open Top Chambers (OTC), and four species for the effect of grazing. Although the species *Euphrasia* does not show significant results, it has also been emphasized in this section.

Effect of experimental warming and year on frequency of occurrence

	Treatment		Year		Treatment x Year	
	Estimate	P- value	Estimate	P- value	Estimate	P-value
S. herbacea	-7.4	0.10	2.44	0.58	-9.44	0.0405
B. vivipara	-6.38	0.12	13.67	0.0019	3.38	0.40
Rumex a.	-6.33	0.15	12.42	0.0082	-6.33	0.16
S. acaulis	2.24	0.55	-3.70	0.32	-8.01	0.0388
Festuca sp.	9.18	0.0147	4.56	0.20	1.93	0.59
Agrostis sp.	-0.93	0.84	6.59	0.17	-0.18	0.96
Euphrasia	-0.44	0.62	1.77	0.05	-0.44	0.62
A. maritima	-0.02	0.83	-0.21	0.83	1.54	0.11
R. acris	2.67	0.14	3.56	0.05	2.66	0.13
Veg. cover	0.19	0.0002	0.094	0.05	-0.02	0.57
S. richness	-0.16	<0.0001	0.061	0.0006	-0.34	0.0411

Table 1, Results for the effects of warming on 9 plant species. Red colour indicates significance in results, and orange indicates a result close to being significant.

Effect of grazing and year on frequency of occurrence

	Treatment		Year		Treatment x Year	
	Estimate	P -value	Estimate	P-value	Estimate	P-value
S. herbacea	3.44	0.38	7.33	0.06	-4.56	0.24
B. vivipara	-0.73	0.82	15.57	<.0001	-1.48	0.66
Rumex a.	-2.18	0.54	21.82	<.0001	3.06	0.39
S.acaulis	12.63	0.0261	5.44	0.32	1.13	0.83
Festuca sp.	-2.70	0.53	2.68	0.52	0.04	0.99
Agrostis sp.	-2.76	0.52	5.76	0.18	-1.01	0.81
Euphrasia	-1.11	0.14	1.11	0.01	-1.11	0.14
A.maritima	-2.041	0.05	2.62	0.0137	-1.29	0.20
R. acris	-0.11	0.78	0.78	0.06	-0.11	0.78
Veg. cover	-0.02	0.69	0.08	0.17	0.03	0.54
S. richness	-0.12	0.03	0.89	<0.0001	0.06	0.60

Table 2, Results for the effects of grazing on 9 plant species. Red colour indicates significance in results, and orange indicates a result close to being significant.

Salix herbacea

The overall occurrence frequency of the species *S. herbacea* was high (Figure 3, A). The non-grazed treatment had the highest frequency and increased the most over the 10-year period. Furthermore, the species showed a significance in the interaction between the warming treatment and year (Table 1), as well as a decrease in cover in the warming treatments from 2007-2017.

Festuca Sp.

For all treatments, the *Festuca* species was reasonably high in abundance within all the plots. (Figure 3, B). A low p-value (Table 1) indicated a significance in the warming treatment, showing an increase in cover, as well as has the highest frequency for both years. This is compared to the other two treatments where the species had not increased over the 10-year period.

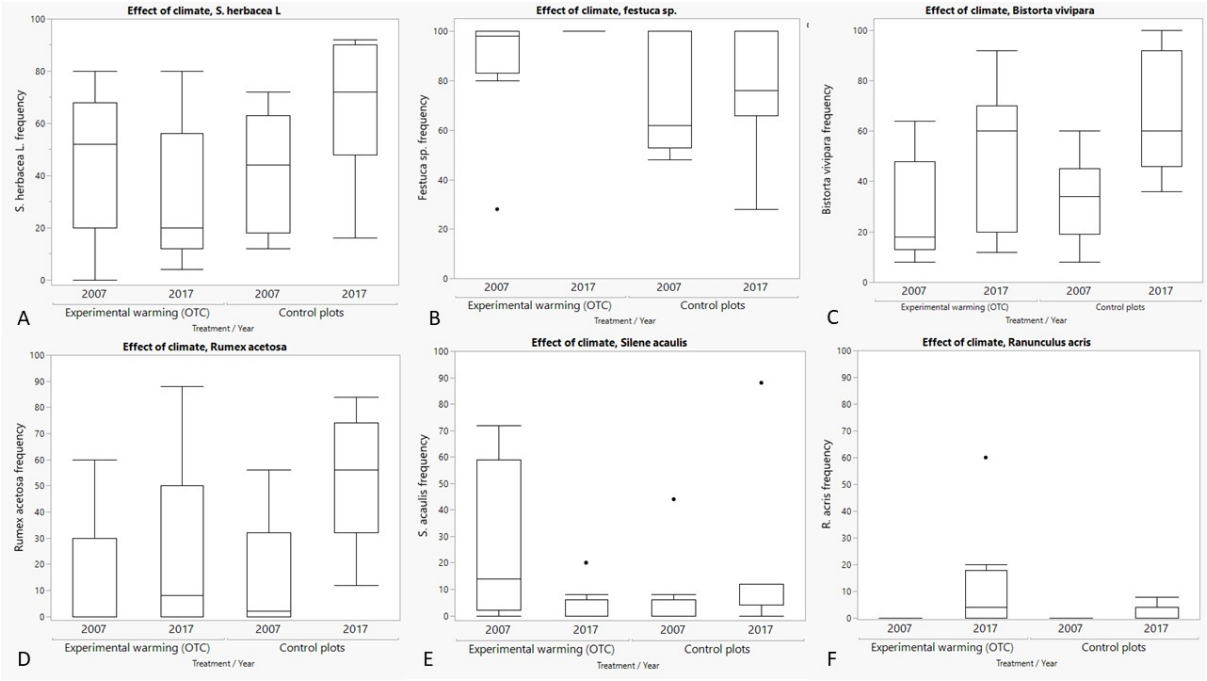

Figure 3, Box plots with the effect of climate on six species, S. herbacea, Festuca sp, B. vivipara, Rumex acetosa, S. acaulis and R.acris. The control plots the same plots as the non-grazing plots for the grazing analysis. The x-axis shows the frequency (0-25) which has been converted to percentage of the different species, and y-axis shows the three treatments as well as the two years chosen.

Bistorta vivipara

All treatments had approximately the same occurrence frequencies, particularly non-grazed and grazed treatments differing only slightly for the year 2007. There was however a large increase between years in every treatment, with 2017 having highest increase (Figure 3, C). The analysis produced a very low p-value, thus indicating significance in the year 2007 (Table 1 & 2), meaning species increased over time and were present in more sub squares in 2017 than 2007. However, there was not much difference in the treatments between the years.

For comparing grazing effects, there was an increase in species frequency in both the grazed and not grazed treatments over the 10-year period (Figure 4, A). Table 2 shows that on average, the species was present in 15% more squares in 2017 than 2007.

Rumex acetosa.

There was a frequency of occurrence increase within the warming and the control treatments, with a significantly higher increase in the control treatment from 2007-2017. The species showed significance in the year in the experimental warming treatment (Table 1), although the frequency remained low for 2007 and 2017 inside the warming treatment (Figure 3, D). The species also showed a significance in the year 2007 (Table 2), meaning that for the year 2007, the grazed treatments possessed a low frequency of *Rumex acetosa*, but a large increase in occurred in 2017, both for the no grazing and grazed treatments (Figure 4, B). The species was on average present in 22% more squares in 2017 than 2007 (Table 2).

Silene acaulis

The warming treatment showed a large decrease from the years 2007-2017, but an overall high frequency of occurrence (Figure 3, E). Results indicate significance in the interaction between the warming treatment and the year 2007 (Table 1).

The grazed treatment had the highest frequency of occurrence, both in 2007 and 2017. There is was very low occurrence in 2007 for the treatment without grazing, with only a small increase in 2017 (Figure 4, C).

Ranunculus acris

There are no records of the species *R. acris* species in 2007, this being the case for all three treatments (Figure 3, F). There was a slightly bigger increase in occurrence frequency in the no-grazed treatment in 2017, than in the grazed treatment in 2017. There was also a slightly bigger species increase of the species in the warming treatment in 2017.

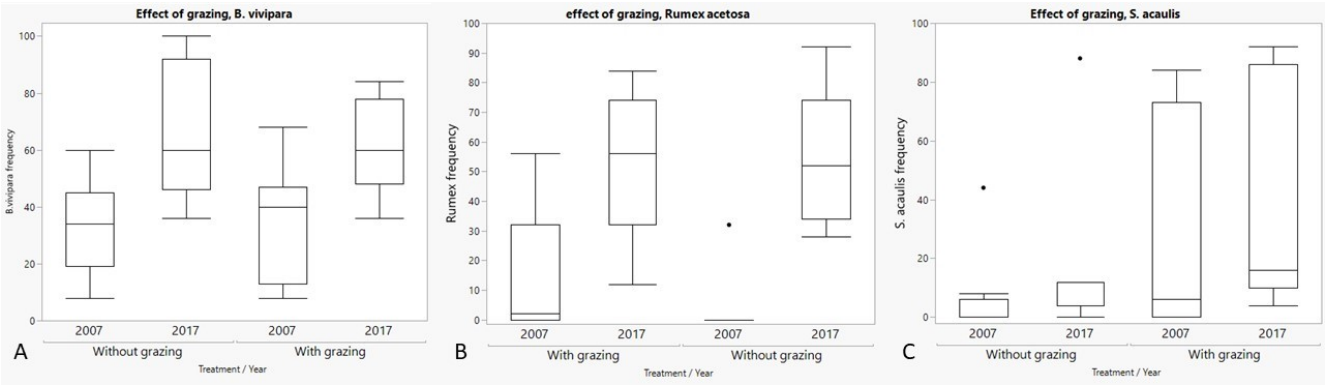

Figure 4, boxplots with the effect of grazing on species B. vivipara, Rumex acetosa and S. acaulis

Armeria maritima

This species was found within the grazed treatments, although the overall count of species was low (Figure 5, B), as there was only an increase of on average 2,6% squares in 2017 compared to 2007, The species was not found in the treatment without grazing in 2007, but in 2017 there was low frequency of occurrence within this treatment.

Euphrasia

This species was only found in the year 2017, and only in the no grazed and warming treatments (Figure 5, A). The overall frequency of occurrence was very low for this species.

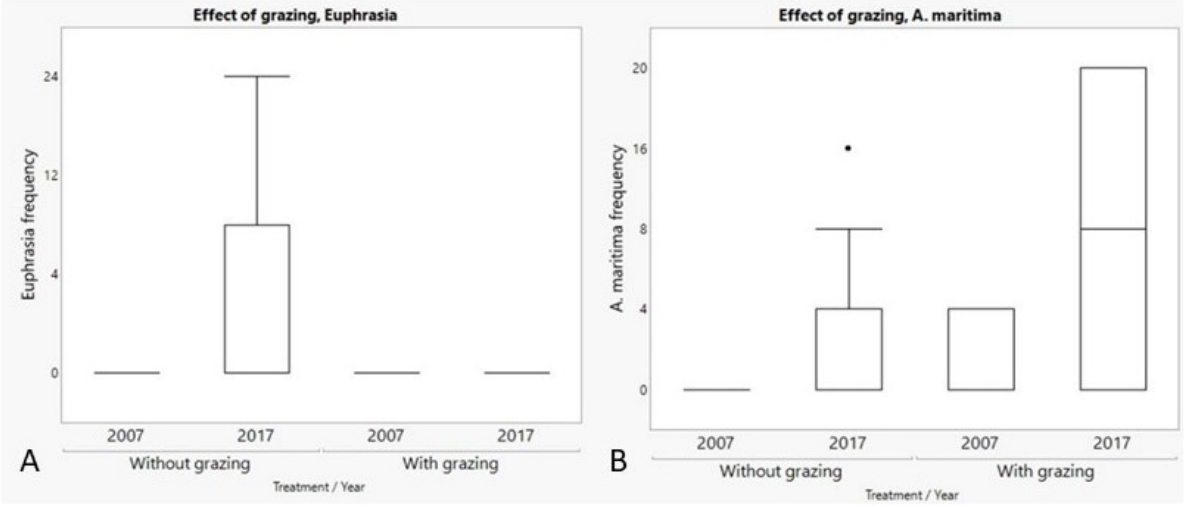

Figure 5, box plots with effects of grazing, Euphrasia and A. maritima

Discussion

The increase in plant species richness has accelerated on mountain summits across Europe during the past decade as a result of climate change (Steinbauer et al., 2018). This means that there has been five times as much species enrichment between 2007 and 2016 as fifty years ago, and summits have gained on average 5.4 additional species (Steinbauer et al., 2018). These findings align with shorter term studies that demonstrate plant community thermophilization (Gottfried et al., 2012), meaning that shifts in distributions are driven by warming (Alstad et al., 2016).

In this study, there was an overall trend of many species increasing their frequency of occurrence over the 10-year period. In other words, most of the plant species examined had a higher rate of growth compared with the amount of grazing which they were subjected to over the 10-year period, slightly increasing in cover from 2007 to 2017. These are surprising results considering the intensity of grazing occurring on the Faroe Islands, for which it was hypothesized several more species would respond negatively (i.e. decrease in abundance over time) to grazing. There is no new research that deals with the effects of herbivory on plant diversity in the Faroe Islands, but similar studies conducted in other global regions state that natural grazing is beneficial for plant diversity but at heavy amounts result in a diversity decline (Olff & Ritchie, 1998b). These findings concur with observations made of the Faroese vegetation; there is no strong indication that the plant diversity is high in more elevated altitudes where grazing sheep are abundant, the dominant vegetation in these areas being the before mentioned grasses

(Fosaa, 2003a). There appears however to be a clear difference between the vegetation diversity between the urban areas that have somewhat excluded grazers and the outer terrains where the sheep have easy access to. Research also suggests that the so called "natural" vegetation now only exists in the inaccessible places on the Faroes (Fosaa, 2001). Another possible reason for the frequency increase could be that the Faroe Islands have experienced a much higher grazing pressure in the past, and what is now being observed in this study is a long-term recovery from this historically higher grazing pressure. One species that was clearly affected by grazing in this study however, *Euphrasia*, was not present in 2007, colonizing only the non-grazed plots during the 10-year study.

Several plant species showed significant responses to warming and grazing. As sample size was rather small, this gave a very clear outcome. A low statistical power was used, which resulted in lower chances for significant results. If the p- value threshold was set at 10% rather than 5%, more significant results in treatments, years, and interaction between the two could have been expected for several more plant species. A larger sample size would presumably also have included several more occurrences of species not abundant in this study. There was also a possibility that some individuals had not been observed in the 2007 photos, due to the lower resolution quality of the photographs. Together these factors may have had an overall influence in the results of this study.

Vegetation cover

It is evident that the cover of bryophytes was higher within the warming treatments, corresponding to different results. Overall vegetation cover has increased to 100% in every warming treatment. It can be presumed that the increase in temperature has resulted in this increase, yet Bjorkman et al. (2020) concluded that experimental chambers can alter other conditions in addition to temperature, and these possibly contributing to unwanted environmental side-effects shown in the vegetation. This correlates well with the OTCs used in this experiment, particularly as the study area is known to be very exposed to harsh weather conditions, such as heavy wind. Within the OTCs wind exposure is altered (no wind inside), and the chambers experience more humidity. It could therefore just as well be these conditions that alter the vegetational state inside the enclosures and not the influenced temperature changes alone.

Salix herbacea showed a negative response to climate warming. A study by Fosaa (2003b) argues that species which are limited in distribution to the uppermost mountain parts will be most threatened by summer temperatures. These species include *S. herbacea* and *B. vivipara*. This experiment showed similar findings, as *S. herbacea* was indeed sensitive to increased warming, though *B. vivipara* did not show a negative response to increased temperature in this study.

Looking at the photographs however, vegetation cover in 2017 was 100% for all plots, compared with much lower covers in 2007 in several of the plots. One reason for the decrease in S*. herbacea* could be the increase in bryophyte growth, which grew to dominate in most of the OTCs in 2017. This finding is in agreement with Alsos et al. (2009), where *S. herbacea* was specified as a poor competitor. Furthermore, this species requires some disturbance to persist. Hence, within the much more stable environments of the OTCs that also exclude grazing, the opposite of an optimal niche was created. It is therefore no certainty that the *S. herbacea* species was negatively affected by experimental climate warming alone. *S. herbacea* was high in number within grazed treatments, indicating that this plant species is abundant. It could thus be concluded from this study, that this is a woody species that grows well in the current Faroese environmental conditions, and this is coinciding with Fosaa's (2001) results based on the same species.

As with *S. herbacea*, many explanations apply to the results of *S. acaulis*. This species responded negatively to increased warming, indicative that this species would not likely be easily adaptable to climate warming. This finding aligns with those of Peterson et al. (2018), which concluded that environmental tolerances that are population-specific will likely shape the response to climate warming of *S. acaulis* across its range, however, further warming could push them into a decline. *S. acaulis* did not seem to be affected by grazing, as the frequency of the species was high in both years for the grazing treatment. This species clearly responds well to stress factors such as grazing, but environmental stress in form of increased temperature creates a negative response.

There is a strong indication that *R. acris* was affected by climate warming because of the rather large increase in occurrence frequency within the warming treatment in 2017 (Figure 3, F), particularly in comparison to the small increases within the other

treatments. This could be evidence of climate adaptability when it comes to warming. This concurs with the findings of Bourdôt et al. (2013), where the potential distribution of *R. acris* in a future climate showed that the climatic niche would remain suitable for this species. However, as said before, the OTCs are not optimal for long-term experimental climate warming experiments, as they are rather small enclosures and alter other environmental factors happening inside the chambers.

There was no indication of *Rumex acetosa* being affected by grazing since the species was high in abundance within in the grazed treatments in 2017. A reason for this increase could be that the species is being grazed but is able to recover better than the others plant species after enduring this stressor. The same can be said about *Armeria maritima,* concerning the response to grazing. This species is therefore able to recover from grazing over the 10-year period, though the recovery is slow, as the overall count of the species was low. Continuing this monitoring experiment could bring insight as to whether this proves to be true.

The experimental plots were set up in 2001, so it could be hypothesized that *Euphrasia* is a species that has a long recovery time, due to its low frequency in the non-grazed treatments in the year 2017. Hellström et al. (2004) have stated that this species is a poor competitor, and that their long-term persistence depends on how well grazing supresses stronger competitors by maintaining low vegetation cover. From the results of this experiment, it could be assumed that as no occurrences were found in the grazed plots in both years, grazing is a dominant factor determining the occurrence of *Euphrasia* in the Faroe Islands. Hellström et al. (2004) further suggested that *Euphrasia* can tolerate minor apical damage relatively well, while more extensive damage could affect their overall performance. If this species is considered an indicator of grazing intensity, it could be concluded that the Faroe Islands are subjective to heavy grazing. As the sample size used was small however, there remains too large of an uncertainty to rely on these conclusions. Another thing to note is the poor quality in the photographs for 2007, making it possible some individuals were not identified in the photographs.

The grass species *Festuca sp.* showed significant response to the warming treatment, increasing more compared with the other treatments. This finding is in agreement with that of Fosaa (2003a) which stated that this species has a large distribution range, and is a fast-growing species that responds positively (i.e. increase in abundance) with

experimental warming. It does not seem to be affected by any applied stress factors. However, the OTCs were completely vegetated in 2017, suggestive that small OTCs can only be used for certain periods of time before they should be "reset". When the OTCs are overgrown by vegetation, it limits the degree to which results can be interpreted.

Auffret et al. (2018) state that specialist flora are significantly more affected than generalists after the loss of open, semi- natural grasslands habitats. The remaining plant species in this study that did not show any notable responses to grazing nor climate could as a result potentially be considered generalists. For example, *Agrostis sp* is one of the most common grass species in the Faroe Islands, with a high reproductive and dispersal rate (Jóhansen et al., 2000). It also possesses a broad distributional range as well and can therefore be considered as a generalist species, compared to *S. herbacea* and *B. vivipara* which are limited in their distribution range (i.e. more specialised). Although *Agrostis sp.* did not show any significant results in this study, the species has demonstrated a variety of responses in other studies. Some have found the abundance and cover to decrease with grazing intensity (Magnússon & Magnússon, 1990) while other have shown the grass to increase when herbivores are removed (Hartley & Mitchell, 2005). A study by Fosaa & Olsen (2007) who used the same study site as in the present experiment showed that *Agrostis canina* and *Agrostis capillaris* differed in their responses, and concluded that a decrease of *Agrostis capillaris* was due to it having higher nutrient requirements than its competitor. Excluding herbivores had had an unintended impact; it had eliminated an important nutrient resource, namely sheep urine and dung, which could make one species more vulnerable than the other. Thus, nutrient availability should also be included as an important factor in future experimental monitoring studies. In this experiment it was not possible to distinguish grass species with certainty in the photographs, which was one downside of using a photograph-dependent method.

Diversity and distribution shifts

Some recent monitoring studies have shown no change in vascular plant diversity across a myriad of tundra sites over the last three decades (Elmendorf et al. 2012b). This is in stark contrast with others focusing on changes in European mountaintop plant communities, where accelerating increases in richness have been found over the past century (Steinbauer et al. 2018). Relating to this study, the warming chambers did not appear to experience a higher diversity than the other treatments but did indeed

experience an increase in biomass. Fosaa & Olsen (2007) had similar findings of a clear biomass increase within the OTCs (length of grass-leaves and vegetation cover) after five years. Over the 10-year period however, an increase in richness was observed for the other treatments. This could mean that time is what influences diversity. In a longer-term future warming scenario, diversity might be expected to decrease, though with an accompanying possible increase in species biomass. An important point to consider however, is whether the occurrences of the *R. acris* had an effect on the drivers of change in this study, meaning that the species was responsible for the increase in richness over time. *R. acris* was not present in the year 2007, but was found in all treatments in 2017, this also being the case for *Euphrasia*, though much less widespread. Since the sample size used was small, these two species could have been enough to affect over the overall results.

The response difference between the arctic and alpine communities could indicate that the dispersal rate of more southernly, warm adapted species is limited when it comes to diversity change in non-alpine tundra communities. It could also be that strong environmental gradients other than temperature (e.g. photoperiod) limit the establishment success of species adapted to warm climates across latitudes from farther south (Bjorkman et al. 2017).

There are numerous reports that focused on the redistribution of plant species towards summits as a result of increasing temperature (Cheng et al., 2011; Steinbauer et al., 2018). There is however a great variation in the rate of change, which suggest that the range shift of each species is dependent on multiple internal species traits as well as external drivers of change (Chen et al., 2011). As mentioned before, no occurrence of the *R. acris* was found in 2007, yet in 2017 species was found in all treatments. It could be hypothesized therefore that this species is susceptible to a distribution shift in future warming scenarios. Although its native range is central and northern Europe (Bourdôt et al., 2013), a distribution shift in this sense could mean an immigration towards higher altitudes. The appearance of this species in the 2017 treatments plots could therefore be the result of an upward immigration in the 10-year span of the monitoring study.

Research by Bourdôt et al. (2013) describes *R. acris* as a plant with the ability to produce a protoanemonin which causes blistering of the lips and tongue as well as intestinal disorders in grazing animals. They further state that the environment's carrying capacity

for grazing livestock has declined as a result of an increase in this species' abundance, as the grazers want to avoid this genus.

If *R. acris* were indeed to increase in abundance and become a more common herb in the higher mountains as a result of warming, there is a possibility that the heavy grazing would decrease as a consequence. For this reason, both inter and intraspecific plant trait differences should be included in future studies to determine whether these traits also factor into the future distributional ranges and plant persistence of the plant species in the Faroe Islands.

As mentioned earlier, climate warming can lead to diversity increase over the long term, which make the species-rich floras move northward (Parmesan, 2006).

Short-term responses to warming however, may be substantially different from long-term trends. This is because immigration is slow relative to local assembly processes (e.g. competition). Evidence of diversity change in terms of plot scales in arctic ecosystems has thus far been mixed (Bjorkman et al., 2020). There are however at least three processes that could generate high diversity of range shift among species. Species may experience time delays in their responses or have physiological constraints limited to each (Chen et al., 2011). Furthermore, if they are habitat specialists or immobile species, they could lag behind in a climate change scenario by failing to colonize across fragmented landscapes (Thomas, 2010), or be composed of traits associated with low colonization and extinction rates, such as poor dispersal ability and low reproductive rate (Angert et al., 2011).

Considering that the diversity increased over time in this short-term study, it could be indicative that the competition is not very high on a local scale. Alternatively, the plants in these alpine environments could be slow growing, suggesting that there is need for a longer monitoring study to get definite results. Theoretically plants with long generation times can experience a delay in extinction following habitat destruction (Kuussaari et al., 2009).

In some cases the effects of the three drivers of global change (i.e. habitat loss, climate change and invasive species), can be immediately seen, but often a considerably longer time period is needed for declining populations to disappear following environmental disturbances (Kuussaari et al., 2009). These delayed extinctions, also called extinction debt, could have played a role in the results of this study. A 16-year monitoring study would perhaps show a general increase in frequency and diversity over time, but it could be that the species will decrease later on as the growing and recovery time for these

plants is slow. Therefore, results could suggest an increase, but over the time, fewer species will be able to persist.

Future vegetational predictions for the Faroe Islands

Future weather predictions for oceanic areas in North Western Europe are expected to include elevated precipitation and cloudiness (IPCC, 2014) and presumably increased wind speed. If the temperature increases, plant species will migrate upwards (Chen et al., 2011). As mentioned earlier, *S. herbacea* and *B. vivipara* are threatened by increased summer temperature because of their low distribution range. It can thus be presumed that these species will not be able to move upward as temperature increases and will therefore become extinct.

Combining future changing weather conditions with the already harsh mountaintop conditions and considering the fact that the mountain environments are prone to soil erosion and grazing, it is highly likely that the Faroe Islands will change over time, with more bare ground being exposed in the future. Heavier precipitation and wind speed combined with grazing would affect shallow root systems decreasing the overall mountainside vegetation cover. Although the coverage results were not significant between the non-grazed and the grazed treatments, it was observed within the photographs that more bare soil was exposed in the grazed treatments. Continuing this monitoring study could aid in spotting any trends that mimic these observations with more certainty.

One must not forget however that species also have individual responses to changing climates, and thus any migration will occur at different rates. Plant species as well as plant communities in the alpine zones are threatened by the encroachment of lower altitude species. Since the vegetation cover in this area is much lower than in the more southernly temperate zone, one possible future scenario could be an abundant invasion in alpine zones. Due to the high frequency of bare soils, there would be less competition from already present species, given that the competitive species can tolerate the harsh environment in this area (Fosaa, 2003b).

Using MacArthur & Wilson (1967) island biogeography theory, it can be hypothesized that since the Faroe Islands are very remote, the plant population gene pool is relatively small. This is attributed to low dispersal rates of plant species, as well as other factors

influencing, such as the small islands sizes. Furthermore, there is a suspicion that low pollinator populations further contribute to the low genetic diversity in the plant populations, resulting in a reliance on clonal reproduction. As a genetically diverse species should be able to better cope with a broader climate conditions in the future (Theodoridis et al., 2018), the plant diversity in the Faroe Islands can thus be expected to be extremely vulnerable to a rapid changing climate, and a large decline in species diversity could be expected to happen on the islands in the future.

Future species competition and conservation measures

For the species in this study that showed negative response to climate warming, namely, *S. herbacea* competition could be a reinforcing factor to the species decline. Diversity was lower in the warming plots while vegetational cover was high, which presumably also contributed to the decrease of plant occurrences within the warming treatments. Taking these environmental stressors into consideration, is can be assumed that this will also result in a diversity decrease in a future with a warmer climate. If plant species move upward competition will increase (as seen in the warming treatment), leading to further decreases in species diversity. Because *S. herbacea* is one of the only woody species found in abundance on the Faroese mountains, it can be expected that the extinction of *S. herbacea* would have dramatic consequences for the overall vegetation on the Faroe Islands and should therefore be included in conservation measures. The presence of trees species is known to reduce soil erosion through root stabilization because of their relatively deep and extensive root systems (Hacisalihoglu, 2007). Conservation efforts should thus have an emphasis on more woody species, like *S. herbacea* since enhancements in productivity and growth are expected from woody plants in future climate warming scenarios (Egelund et al., 2012). Promoting *S. herbacea* could prevent erosion, lead to increased habitat heterogeneity, and improve resilience and diversity of plant communities of the Faroe Islands (Egelund et al., 2012).

Grazing resilience in the Faroese mountains

The vegetation on the Faroese islands has been under the influence of grazing livestock since the first settlement (Jóhansen, 1985). It could be hypothesized that over the centuries local plants have adapted some form of resilience to grazing, since the results of this experiment were much less dramatic than expected. A form of co-evolution could have taken place over time while the islands' sheep increased in number over time, many plants still remain and are resilient towards grazing.

It has been suggested that species rich plant communities are more resilient or resistant to disturbance (Mulder, 1999). Since there is no doubt that the overall Faroese plant diversity has decreased over the years as a result of heavy grazing (Jóhansen, 1985), it can be hypothesized that a further decreases in diversity over time will lead to a decrease plant populations resilience. Several plant species now currently considered as rare, and/or only found on cliff sides, where sheep do not have access to (Jóhansen, 1985). To emphasize an earlier statement, continuing this monitoring study into the future will unquestionably show results that differ from the short-term results.

Methodology: strengths and weaknesses

The method developed for this study using digital quadrats for plant identification demonstrated both strengths and weaknesses, as mentioned throughout the earlier discussion. First, it is only possible to count the presence or absence of species and estimate overall vegetation cover from digital photographs. Thus, leaf length, plant height and other functional plant traits cannot be measured. Second, there is the possibility that not all species are identifiable by photograph, particularly different grass species with very similar characteristics. Species that are easy identifiable and visible should therefore be chosen for this method to ensure the most accurate outcome. On the other hand, this method is very time efficient. Field time can be shortened, and more ground covered as the identification can be done digitally, rather than by estimation in the field. This is especially convenient in the Faroe Islands, where the weather can include all seasons in one day.

The photographs used for data collection in this study were not originally intended for this method. It was therefore difficult to create accurate quadrates on a few photographs and the resolution varied between the photographs. For future studies, photographs should be taken with the intention of using a digital quadrat system, as this method could prove to be a helpful tool for quick estimates of plant diversity and vegetation cover. It would ensure less man hours as well as time efficiency (i.e. more ground covered in less time).

Another important note to add is that there were no OTC outside the fenced area in the experimental monitoring set-up for this study, meaning that no OTC were exposed to grazing. It was thus only possible to test the effects of grazing, and the effects of warming

in the absence of grazing. To be able to study the interactive effects of warming and grazing explicitly, a solution setting up OTCs that can tolerate the presence of grazers should be found and implemented into future studies.

Conclusion

Although the Faroe Islands are heavily grazed, this study found that several plant species are not affected by grazing with regards to relative abundance, the possible reasons being manifold. One is that the plant species have adapted to withstand a certain degree of grazing since they have coexisted with sheep on the islands for centuries. Another possibility is the plant community is recovering from an earlier period with hypothesized much higher grazing pressures, leading to treatments responding with increased cover over time. Therefore, the more likely explanation is that the observed results after a 10-years display only show the short-term plant responses which may differ substantially over a longer period.

The experimental warming treatments also gave some interesting results in that *S. herbacea* had a negative response to experimental warming, concurrent with other studies that have concluded this species would be threatened in a future warming scenario.

Continuing this monitoring experiment is essential in order to fill the knowledge gap that exists between the interactions of grazing and climate change and how these two reinforcing factors affect the mountain biota in the Faroe Islands. Furthermore, by placing this research into a global context could help connect the reasons behind the driving factors driving environmental change in a remote region such as the North Atlantic, where potential climate consequences are still largely unknown.

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